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THE DISTORTION OF TIDAL CURRENT IN THE MAHAKAM ESTUARY, EAST KALIMANTAN, INDONESIA

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Abstract

Two-dimensional barotropic hydrodynamical model ECOMSED (Estuarine Coastal and Ocean Modeling System with Sediment) developed by HydroQual, Inc., (2002) has been applied to the Estuary of Mahakam Delta, East Kalimantan, Indonesia, to study the dynamics of tide and tidal current in this region. The model was run for 15 days (27 June – 12 July 2003) using river discharge and tides as generating forces.

Wave form is changed from the mouth of the estuary to upstream. The natural oscillation period of the Mahakam Delta T_n is 19 hrs. T_n is near the period of diurnal tide and far from that of semi-diurnal tide. The decrease of semi-diurnal M_2, and S_2 amplitudes in the estuary is larger than that of diurnal (K_1, O_1) ones. The M_4 tidal current amplitude follows the M_2 tidal amplitude distribution, peaking at mid estuary, whereas M_4 tidal elevation amplitude is greatest farther to upstream. In the Mahakam estuary, tidal elevation amplitude distortion (M_4/M_2) is less than 0.3. For current amplitude, M_4/M_2 reaches a maximum of 1.85 about 40 km from the head of the estuary.

The delta acts as a frictionally dominated zone that modifies the tidal wave from a simple sinusoid to one with ebb currents that accelerate to maximum early in the tidal cycle and last more than one-half of the tidal cycle. Along smaller side channels, the tidal currents favor stronger flood or ebb currents, depending upon the local surrounding morphology.

***Keywords** : numerical model, Estuary of Mahakam Delta, Tide, Cohesive sediment transport, and river discharge.*

1. Introduction

Estuaries, which act as the transition zone between the upland wetlands and the coastal ocean, are important nursery regions and feeding grounds for a very large number of marine species. Estuaries can be characterized by their geomorphology and their pattern of salinity stratification (Hansen and Rattray, 1966). In coastal plain estuaries, the vertical distribution of salinity is regulated primarily by the volume of freshwater outflow and the magnitude of the tidal current (Leonard, 1976). The constant mixing between freshwater and seawater results in a variable environment in estuaries. Numerous physical factors including the volume of river discharge, intensity of tidal action, tidal currents and elevations, the composition of the sediments, and wind and wave energy contribute to the overall complexity of these coastal environments. The interaction of river flow, tidal currents, and basin morphology produces the type of circulation and related salinity structure characteristic of a particular estuary that affects the species composition and distribution of flora and fauna.

Tides are the periodic rise and fall of the sea level due to attractive forces of the sun, moon, and earth. Tides and tidal currents are a major source of energy for turbulence and mixing in estuaries and they play an important role in the movement of dissolved and particulate material, creating oscillatory fluxes in physical and chemical properties. The dissipation of tidal energy causes changes in the vertical stability of the water column. Denman and Powell (1984) showed that tidal mixing is important for phytoplankton and primary productivity because it produces light and nutrient fluctuations.

The Mahakam Delta, located on the east coast of Kalimantan, Indonesia, is an active delta system which has been formed in humid tropical environment under condition of relatively large tidal amplitude, low wave-energy, and large fluvial input (Fig.1(a)). The Mahakam estuary is influenced by tides and tidal currents from the Makassar Strait. The tides in the Makassar Strait are semi-diurnal with a considerable diurnal inequality. Tidal amplitude ranges from less than 0.2 m during the neap tide to about 0.6 m during the spring tide, which occur with a 15-day periodicity (Allen and Chambers, 1998). Although such tidal amplitudes are not very large, they are sufficient to generate strong tidal currents which lead to reversing the flow direction of the Mahakam river as far upstream as Samarinda, located about 20 km upstream from the delta apex (**Fig. 1(b)**). The wave energy that affects the delta is very low. Low wind speed and the short fetch in the Makassar Strait result in a significant wave height of less than 0.6 m (Roberts and Sydow, 2003). Furthermore, the shallow submerged delta-front platform, which extends to the 5 m isobath several kilometers offshore ***(Fig.1(b))***, dissipates wave energy so that only low-energy waves reach the coastline.

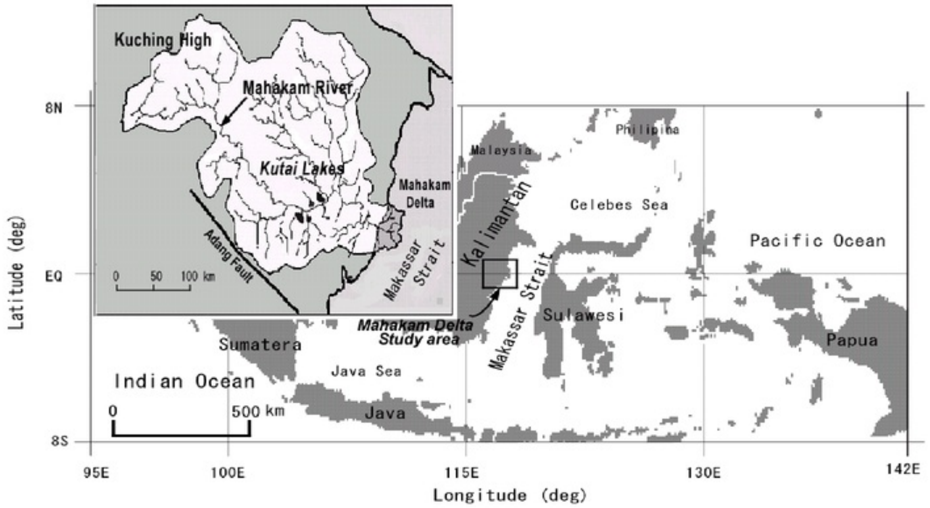

Fig. 1(a) Location map of the Mahakam delta (study area) on the east of Kalimantan, Indonesia and Mahakam River Drainage Basin (Allen and Chambers, 1998).

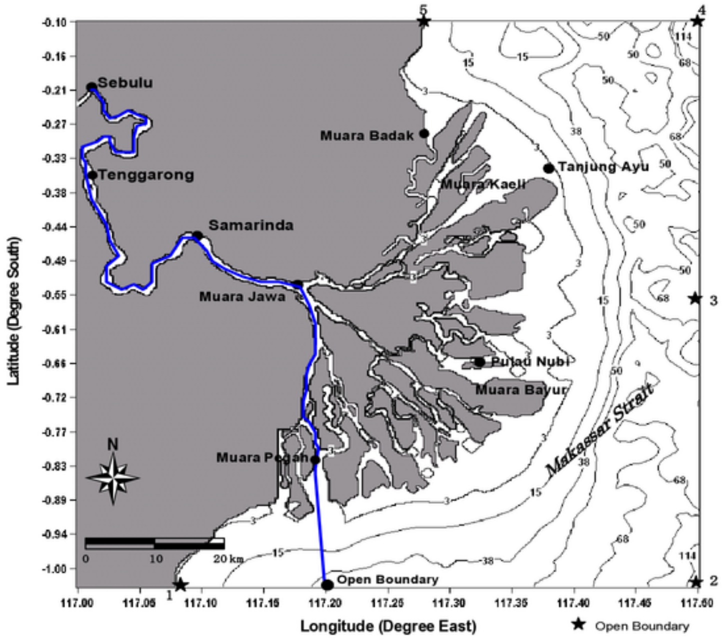

Fig. 1(b) Bathymetric map of the Mahakam Estuary from DISHIDROS of Indonesian Navy. Numbers show the depth in meters.

The present Mahakam river drains about 75,000 km^2 of the Kutei Basin shown in Fig. 1(a) was a part of the uplifting central Kalimantan ranges. From available rainfall data and the size of the drainage basin, a mean water discharge was evaluated as the order of value ranging from 1800 to 2800 m^{3}s^{-1} with large seasonal variations (Allen and Chambers, 1998). Floods up to 5000 m^{3}s^{-1} may occur in the upper and middle reaches of the catchment, which is separated from the river mouth of the drainage basin by a subsiding area characterized by a low relief alluvial plain and several large lakes, located about 150 km upstream of the delta plain (Roberts and Sydow, 2003). The lakes create a buffer causing the damping of the flood surges (Storms et al., 2005) and effectively level the Mahakam river floods, resulting in a constant discharge for lower reaches of the Mahakam river and delta system. The absence of peaks in river discharge has resulted in a delta plain that has no natural levees or crevasse splays. The climatic conditions are tropical, with only a slight monsoon impact. Rainfall ranges from about 4000 to 5000 mm per year in the central highlands to 2000 to 3000 mm per year near the coast (Roberts and Sydow, 2003) and has a high in January and a low in August. The objective of this study was to characterize variations in the tidal current and to examine how the estuarine circulation is related to tidal cycles during the flood and ebb seasons based on these observations. The used hydrodynamical model is a state of the art two dimensional time dependent model. This module of ECOMSED (Estuarine Coastal and Ocean Modeling System with Sediment), developed by HydroQual, Inc., (2002), has been successfully applied to the coastal and estuarine waters. Some recent applications of the module include Chesapeake Bay (Blumberg and Goodrich, 1990), Delaware Bay and Delaware River (Galperin and Mellor, 1990), the Gulf Stream Region (Ezer and Mellor, 1992). The development of ECOMSED was originated in the mid 1980's with the creation of the Princeton Ocean Model (Blumberg and Mellor, 1987).

2. Observation

Bathymetry data of the model domain were obtained from DISHIDROS (Indonesian Navy Hydrographic Department) of Indonesian Navy (**Fig. 1(b)**). The model domain in this study covers the area of Mahakam delta (0°10'00''S – 1°03'00''S and 116°59'00''E – 117°49'14''E), offshore area of approximately 30 km from Muara Bayur toward the Makassar Strait and toward upstream from Muara Pegah up to Sebulu which passes through the Samarinda city (**Fig. 1(b)**).

The series of water surface elevation and current data were obtained from the IMAU (Institute for Marine and Atmospheric Research Utrecht University, the Netherland) which conducted the field observation in the Mahakam delta during the period of 30 June –8 July 2003 (the south east monsoon). Water surface elevation and current velocity were measured using a pressure sensor and ADCP (the Acoustic Doppler Current Profiler), respectively. The data were sampled at Muara Jawa (Fig. 1(b)) at the depth of 4.0 m from the surface and utilized to verify and validate the model results.

3. Numerical Simulation

3.1 Governing Equations

The tide-induced motion in the coastal sea is generally described by the conservation law of momentum and water mass. They are the equations of motion along E-W ($\overline{U}$) and N-S ($\overline{V}$) directions,

$$\frac{\partial \overline{U}}{\partial t}+\frac{\partial \overline{U}^{2}}{\partial x}+\frac{\partial \overline{U}\,\overline{V}}{\partial y}-f\overline{V}=-g\frac{\partial \eta}{\partial x}+\frac{\tau_{bx}}{\rho_{o}D}+A_{H}\Delta\overline{U}, \qquad (3.1)$$

$$\frac{\partial \overline{V}}{\partial t}+\frac{\partial \overline{U}\,\overline{V}}{\partial x}+\frac{\partial \overline{V}^{2}}{\partial y}+f\overline{U}=-g\frac{\partial \eta}{\partial y}+\frac{\tau_{by}}{\rho_{o}D}+A_{H}\Delta\overline{V}, \qquad (3.2)$$

and the continuity equation:

$$\frac{\partial D\overline{U}}{\partial x}+\frac{\partial D\overline{V}}{\partial y}+\frac{\partial \eta}{\partial t}=0 \quad , \qquad (3.3)$$

where $\overline{U}$ and $\overline{V}$: the vertically integrated velocities in x and y direction [ms^{-1}]
D : the total depth (= H + η)
H : the depth
η : the surface elevation
τ and τ_{y} :the bottom stress in x and y direction($=\rho_0\gamma_b^2\left(\overline{U}\ \sqrt{\overline{U}^2+\overline{V}^2}\right)$
and $=\rho_0\gamma_b^2\left(\overline{V}\sqrt{\overline{U}^2+\overline{V}^2}\right)$)
ρ_0 : the density of water (=1024.78 kg m^{-3})
γ_b^2 : the bottom frictional coefficient (= 0.0025)
A_H : the coefficient of horizontal eddy viscosity [$m^2\,s^{-1}$]
g : the gravitational acceleration [9.8 ms^{-2}]
f : the Coriolis parameter (= 2Ω sin ϕ; Ω = 7.27 x $10^{-5}s^{-1}$ and ϕ is the latitude)

Δ : the Laplace Operator for 2 Dimensional ($= \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$).

The horizontal eddy viscosity is given on the basis of Smagorinsky formula,

$$A_H = C\Delta x\Delta y\left[\left(\partial\overline{U}/\partial x\right)^2 + \left(\partial\overline{V}/\partial y + \partial\overline{U}/\partial y\right)^2/2 + \left(\partial\overline{V}/\partial y\right)^2\right]^{1/2}, \qquad (3.4)$$

where C is a constant (= 0.20) and Δx and Δy are horizontal mesh sizes (Δx=Δy = 200 m).

3.2 Boundary Conditions

Along the open boundary, the tidal elevation is prescribed by the linear interpolation using harmonic constant of M_2, S_2, K_1 and O_1 constituents at five points (1, 2, 3, 4, 5) with star marks (see Fig. 1(b)) given by ORI.96 model, which are shown in Table 1. ORI.96 ocean tide model was developed at Ocean Research Institute, University of Tokyo. The ORI.96 model provides grid values of harmonic constants of pure ocean tide (0.5 x 0.5 degrees) and radial loading tide (1 x 1 degrees) for 8 major constituents (Matsumoto et al., 1995).

Table 1. The amplitudes and phase (referenced at GMT + 08.00) of the 4 dominant harmonic constituents along the open boundary from Tide Prediction Model ORI. 96 (ORI, Tokyo Univ.).

Constituent	**Amplitude and Phase**	**Sta. 1**	**Sta. 2**	**Sta.3**	**Sta.4**	**Sta.5**
S_2	Amplitude (m)	0.465	0.468	0.468	0.478	0.478
	Phase(deg)	322.57	322.54	322.54	322.57	322.50
M_2	Amplitude (m)	0.699	0.699	0.699	0.646	0.647
	Phase (deg)	276.88	276.04	276.04	278.38	278.37
K_1	Amplitude (m)	0.221	0.224	0.224	0.211	0.211
	Phase (deg)	159.02	160.27	160.27	156.66	156.40
O_1	Amplitude (m)	0.164	0.165	0.165	0.159	0.159
	Phase (deg)	139.36	140.45	140.45	137.22	137.03

The averaged monthly river discharge data of the Mahakam river (1993 – 1998) obtained from the Research and Development Irrigation Ministry Public Work, Republic of Indonesia. The average river discharge in June and July 2040 $m^3 s^{-1}$ was given at Sebulu in **Fig. 1(b)**.

4. Results

4.1 Verification Current Velocity

The current verification of simulation result was conducted at Muara Jawa (**Fig. 1(b)**). Verification graph was shown in **Fig. 2**. The current velocity component of x direction (U; eastward) indicates that simulation results are a little bigger than the observation data. Figure 4 shows that x component has an appropriate phase with observation data in almost every condition with RMS error of 0.05 ms^{-1}.

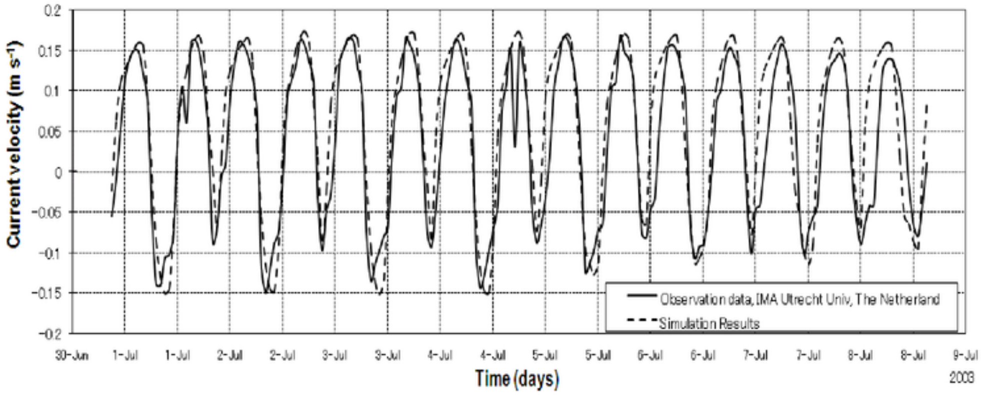

Fig. 2 Verification of the current velocity component U (x direction, east (+) – west (-)) between the observation data (IMAU Utrecht Univ.) and the simulation results at Muara Jawa at the depth of 4.0 m from the surface for the period of 30 June to 08 July 2003.

4.2 Tidal Current

The spatial variations in calculated tidal current amplitudes are shown in **Fig.3**. The semi-diurnal and diurnal tidal currents amplitude increases significantly from the open boundary towards Muara Pegah. Furthermore it decreases significantly from Muara Pegah towards upstream. The tidal current amplitude is strongly influenced by the cross sectional area and the friction.

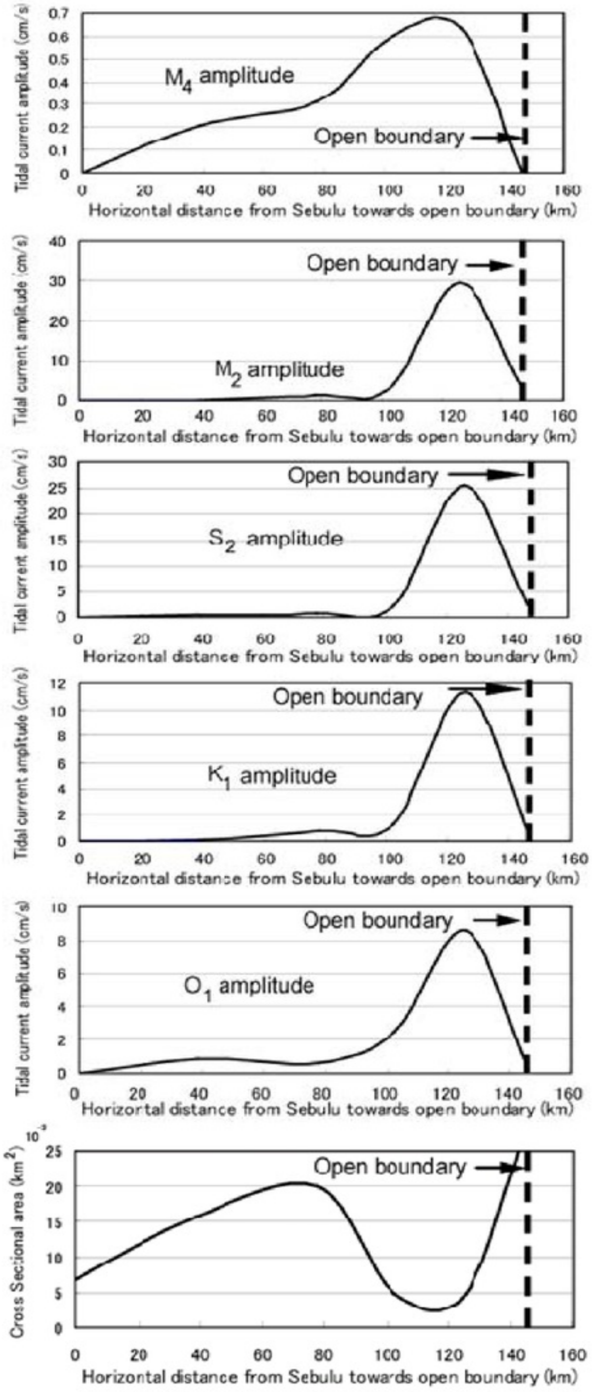

Fig.3 Spatial variation of M_4, M_2, S_2, K_1, and O_1 tidal current amplitudes and cross-sectional area along the axis of the Mahakam estuary.

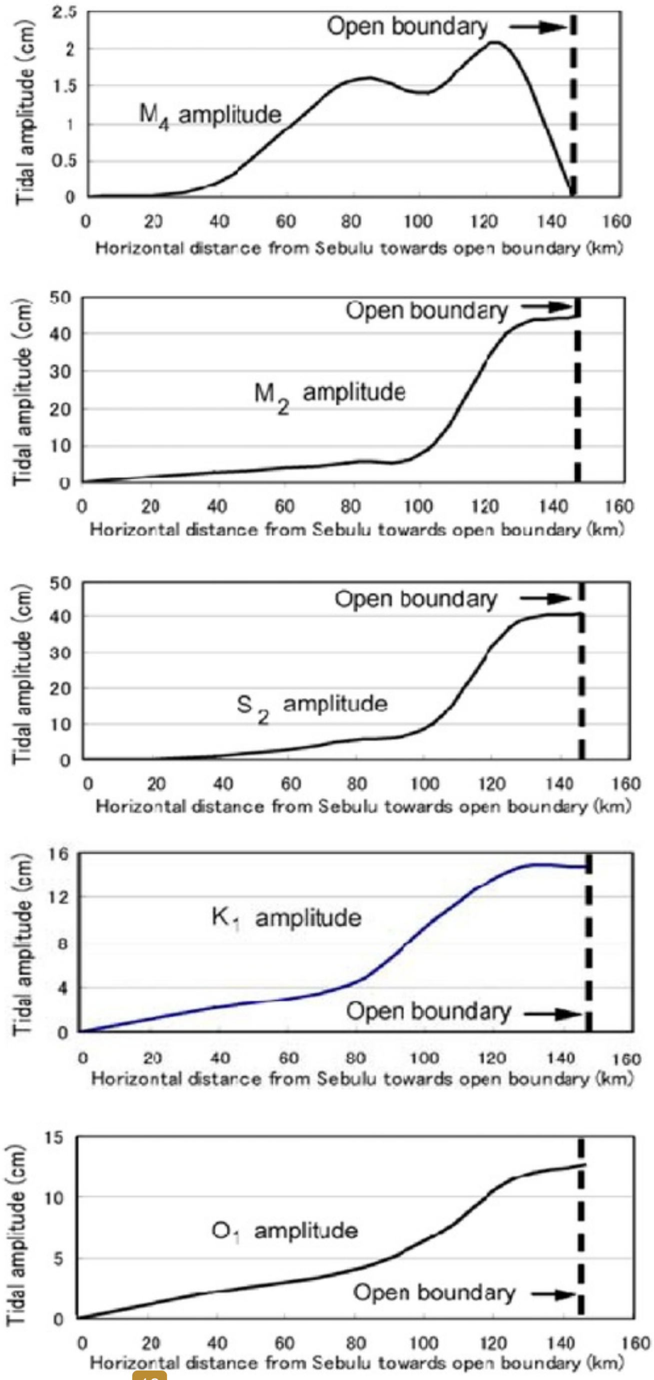

Fig. 5 Spatial variation of M_4, M_2, S_2, K_1, and O_1 tidal amplitudes along the axis of the Mahakam estuary.

The M_4 tidal current amplitude distribution follows the M_2 tidal current amplitude distribution with its peak at mid estuary (about 120 km from Sebulu), whereas M_4 tidal elevation amplitude has another peak farther upstream (about 80 km from Sebulu) as shown in **Fig.** 4. This is due to the shrinking of the cross-sectional area from 60 km to 80 km from Sebulu as shown in **Fig. 3**.

In the Mahakam estuary, tidal elevation amplitude distortion (M_4/M_2) is less than 0.3 as shown in **Fig.5**. For tidal current amplitude, M_4/M_2 reaches a maximum of 1.85 at Tenggarong (about 40 km from Sebulu) due to the decrease of the cross-sectional area from Samarinda to Tenggarong.

The distortion of M_2 tidal wave in shallow estuaries plays an important role in sediment and salt transport (Blanton et al. 2002). Factors such as friction and channel morphology generate shallow water overtides such as M_4 constituent.

Figures 6 show the spatial variations in the mean sea level, the averaged tidal current kinetic energy along the axis of the Mahakam Estuary. The averaged tidal current kinetic energy is nearly zero at open boundary, becomes 0.67 $(ms^{-1})^2$ at Muara Pegah but decreased towards upstream and it is almost zero at Sebulu.

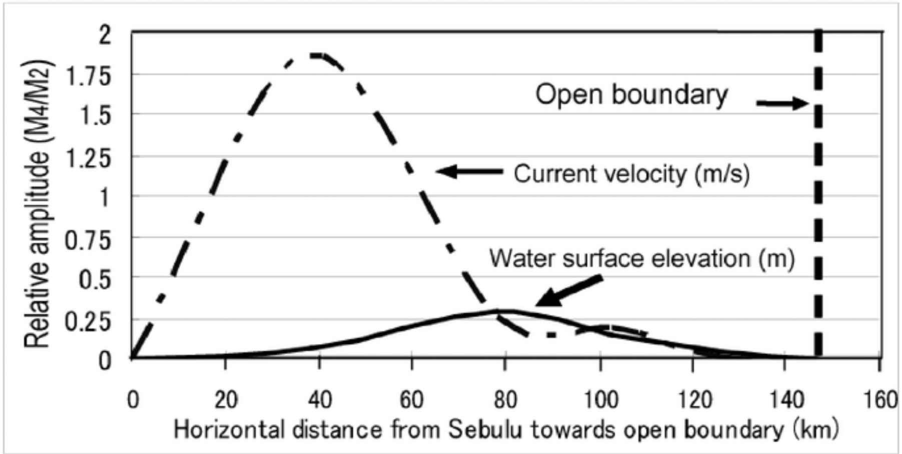

Fig. 5 Spatial variations of M_4/ M_2 tide and tidal current amplitudes along the axis of the Mahakam estuary.

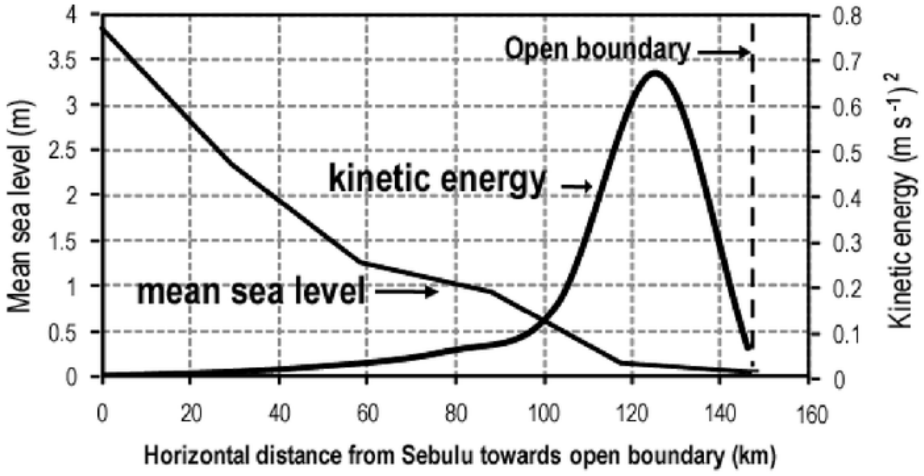

Fig. 6 Spatial variation of mean sea level and the averaged tidal current kinetic energy along the axis of the Mahakam estuary

5. Discussion

In this numerical simulation the results clearly indicate that the tide is the main driving force affecting the water level in the Mahakam estuary. The currents in the Mahakam delta waters are mostly affected by tides and river flow. During the flood tide the current flows to the delta waters, and vice versa in the ebb tide. Such tidal current occurs according to the tidal wave behavior in the Mahakam delta.

The RMS (root mean squared) error in the model current velocity are 0.05 ms^{-1}, with the tidal current amplitude of 0.15 ms^{-1}.. The semi-diurnal (M_2, S_2) tidal amplitude peaks at the open boundary and then it begins to decrease steadily upstream along the main stream of the Mahakam river. The diurnal (K_1,O_1) tidal amplitude peaks between the open boundary and Muara Pegah. The decrease of diurnal tidal amplitude is smaller than that of the semi-diurnal tidal amplitude. This is due to the natural oscillation period of the Mahakam Estuary (19 hrs) is near the diurnal tidal period but is far from the semi-diurnal tidal period. In the Mahakam estuary, tidal amplitude distortion (M_4/M_2) is less than 0.3.

6. Reference

Allen, G.P., and Chambers, J.L.C., 1998. Sedimentation in the Modern and Miocene Mahakam delta, Jakarta, Indonesia Petroleum Association, Field Trip Guidebook.

Blumberg, A.F., and G. L. Mellor., "A description of a three-dimensional coastal ocean model. In: Coastal and Estuarine Sciences 4, Three-Dimensional Coastal Ocean Models", American Geophysical Union, Washington D.C, 1987, pp. 1 – 20.

Blumberg, A.F., and D.M. Goodrich.," Modeling of Wind - Induced Destratification in Chesapeake Bay". Estuaries, 13, 1990, pp. 1236 – 1249.

Blanton J, Lin G, and Elston S., "Tidal current asymmetry in shallows estuaries and tidal creeks". Cont. Shelf Res. 22, 2002, pp. 1731 – 1743.

Ezer, T. and Mellor G.L.," A Numerical Study of the Variability and the Separation of the Gulf Stream, Induced by Surface Atmosphere Forcing and Lateral Boundary Flows". J. Phys. Oceanography 22, 1992, pp. 660 – 682.

Galperin, B., and Mellor G.L., "A Time Dependent, Three-Dimensional Model of the Delaware Bay and River System", Estuarine, Coastal Shelf Sci,31, 1990, pp. 231 -281.

HydroQual, Inc.," A primer for ECOMSED, Users Manual", Mahwah, N. J. 07430, USA, 2002.

Mandang, I., and Yanagi, T., "Tide and tidal current in the Mahakam Estuary, East Kalimantan, Indoensia", Coastal Marine Science, 32, 1, 2008, pp. 1 - 8.

Matsumoto, K., Ooe, M., Sato, T., and Segawa, J., "Ocean tide model obtained from TOPEX/POSEIDON altimetry data", J. Geophys. Res, 100(C12), 1995, pp. 25319 – 25330.

Roberts, H.H., and Sydow, J., 2003. "Late Quaternanry stratigraphy and sedimentology of the offshore Mahakam delta, East Kalimantan (Indonesia)". In: Sidi, F.H., Nummedal, D., Imbert, P., Darman, H., Posamanetier, H.W. (Eds) Tropical Deltas of Southeast Asia; Sedimentology, Stratigraphy, and Petroleum Geology, SEPM Special Publication, 76, 2003, pp. 125 – 145.

Storms, J.E.A., Hoogendoorn, R.M., Dam, R.A.C,. Hoitink, A.J.F., Kroonenberg, S.B., "Late-Holocene evolution of the Mahakam delta, East Kalimantan, Indonesia", Sedimentary Geology, 180, 2005, pp. 149 -166.

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